

Review of the Effects of Rotenone on Aquatic Invertebrates

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Introduction

Rotenone is a naturally occurring compound that is found in many plants in the family Leguminosae (Vinson et al. 2010). Plants in this family are typically found in tropical areas and as a result, rotenone has been used to collect fish by people in these regions for centuries. Over the past 100 years, rotenone has been widely used by fisheries managers to sample fish or to "renovate" waters that contain un-desirable fish species. Several manufacturers produce rotenone, but generally, only three forms of the chemical are available to fisheries managers: 1) a 5% powder, 2) a liquid containing 5% rotenone, and 3) a liquid containing 2.5% rotenone + 2.5% of a synergist (Finlayson et al. 2000). These chemicals are typically applied at concentrations of 1-5 mg/L (0.025-0.25 mg/L of active product). Rotenone kills fish by inhibiting key respiratory enzymes, essentially killing them through oxygen deprivation (Chandler 1982).

Rotenone is relatively non-toxic to plants and mammals. The chemical is extremely toxic to fish. The toxicity of the chemical to aquatic invertebrates varies among taxa. Regardless, the consensus in the literature is that rotenone is more toxic to invertebrates than it is to mammals, but less toxic than it is to fish. The purpose of this review is to summarize what is known about the toxicity of rotenone to aquatic invertebrates and to compare to toxicity of rotenone between fish and invertebrates.

Laboratory Studies

The sensitivity of aquatic invertebrates to rotenone has been established through several laboratory studies. Chandler (1982) determined 96 h LC50 values for a number of invertebrate taxa. The most sensitive taxa tested was *Daphnia pulex* (LC50 < 0.0275 mg/L) and the least sensitive was the snail *Heliosoma* sp. (LC50 = 7.95 mg/L). The LC50 values reported for *Hydropsyche* sp. caddisflies was 0.605 mg/L, 0.340 mg/L for ostracods, and 2.0-7.5 mg/L for three tested bivalve species (Chandler 1982). Finlayson et al. (2010) determined 8 hr LC50 values for various Trichoptera, Ephemeroptera, and Plecoptera species (two species from each taxa). The results varied with species and rotenone manufacturer, but, Ephemeropteran species were the most sensitive (LC50= 0.26-0.80 mg/L) and the Plecopterans were the least sensitive (LC50= 1.14-2.04 mg/L). As part of this study, Finlayson et al. (2010) evaluated the effect of the rotenone synergist piperonyl butoxide and found that this synergist did little to increase the toxicity of rotenone to rainbow trout *Oncorhynchus mykiss* but did increase the toxicity of the piscicide to invertebrates. Meadows (1973) determined the toxicity of rotenone to *Cyclops* sp., *Asellus aquaticus*, and *Gammarus pulex*. The zooplankton (*Cyclops* sp.) died under all the conditions tested. A high percentage (90%) of *Gammarus pulex* were able to survive six days of treatment at a rotenone concentration of 2.0 mg/L. *Asellus aquaticus* was less tolerant of the treatment; 70% of individuals survived for six days at a concentration of 0.5 mg/L. Rach et al. (1988) estimated the 48 hr LC50 for *Daphnia magna* to be 0.074 mg/L.

Table 1 provides LC50 values for numerous aquatic invertebrate taxa. The data in the table were compiled from numerous sources. Vinson et al. (2010) also provides a review of laboratory studies

that have evaluated the toxicity of rotenone to invertebrates. In addition, the authors concluded that: 1) little research on the toxicity of rotenone to lotic invertebrates has been conducted, 2) there is a wide range of sensitivity within and among taxa, 3) benthic invertebrates are less sensitive than planktonic invertebrates, 4) smaller invertebrates are more sensitive than larger ones, 5) invertebrates that use gills are more sensitive than those that extract oxygen cutaneously, and 6) lotic species are more sensitive than lentic species.

Table 1: Estimated LC50 values for the application of rotenone for various aquatic invertebrates.

Group	Species	Test Endpoint (hours)	Lethal Concentration (mg/L)
Flatworm	<i>Catenula</i> sp.	24	5.10
	<i>Planaria</i> sp.	24	<0.50
Annelid Worms	Leech	48	<0.10
Copepod	<i>Cyclops</i> sp.	72	<0.10
Branchiura	<i>Argulus</i> sp.	24	~0.025
Cladoceran	<i>Daphnia magna</i>	48	0.07
	<i>Daphnia pulex</i>	24	0.03
	<i>Diaptomus siciloides</i>	24	<0.025
Ostracod	<i>Cypridopsis</i> sp.	24	0.49
Conchostracan	<i>Estheria</i> sp.	24	~0.050
Freshwater Prawn	<i>Palaemonetes kadiakensis</i>	24	5.15
Crustacean	<i>Asellus aquaticus</i>	144	<0.50
	<i>Cambarus immunis</i>	72	>0.50
	<i>Gammarus pulex</i>	144	> 2.0
Dragonfly Naiad	<i>Macromia</i> sp.	24	4.70
Stonefly Naiad	<i>Pteronarcys californica</i>	24	2.90
Backswimmer	<i>Notonecta</i> sp.	24	0.100-3.42
Caddis Fly Larvae	<i>Hydropsyche</i> sp.	96	0.61
Whirligig beetle	<i>Gyrinus</i> sp.	24	3.55
Water Mite	Hydrachnidae	96	~0.050
Snail	<i>Physa pomilia</i>	24	6.35
	<i>Oxytrema catenaria</i>	96	1.75
	<i>Lymnaea stagnalis</i>	96	>1.00
	<i>Heliosoma</i> sp.	24	30.00
Bivalve Mollusc	<i>Dreissena polymorpha</i>	48	0.22
	<i>Obliquaria reflexa</i>	48	>1.00
	<i>Elliptio buckleyi</i>	96	2.95
	<i>Elliptio complanata</i>	96	2.00
	<i>Corbicula manilensis</i>	96	7.50

Generally, the toxicity of rotenone to fish is at least 2 orders of magnitude greater than the toxicity of the piscicide to aquatic invertebrates. Among various fish taxa, cyprinids and catfishes are more tolerant than centrarchids, catostomids, perch, and salmonids to rotenone treatment (Table 2). Salmonids are more susceptible to the application of rotenone than most other fish taxa (Table 2).

Table 2: LC50 values for various fish species. The test endpoint (h) for the calculation of LD50 values and temperature is noted. NR represents situations where temperature was not reported.

Group	Species	Test Endpoint (hours)	Temperature (°C)	Lethal Concentration (µg/L)
Salmonidae	<i>Oncorhynchus tshawytscha</i>	24	12	5.6
	<i>Oncorhynchus mykiss</i>	3	12	8.8
		3	17	3.7
		24	12	3.4
		24	17	2.2
		48	17	2
		96	12	2.3
		96	17	2.2
	<i>Salmo trutta</i>	1	17	5.5
Cyprinidae	<i>Carassius auratus</i>	96	12	24.9
	<i>Ctenopharyngodon idella</i>	6	11	24.5
	<i>Cyprinus carpio</i>	6	12	13.5
		24	11	30.5
		24	12	4.2
		96	12	2.5
	<i>Notemigonus crysoleucas</i>	72	20	23.5
	<i>Pimephales promelas</i>	72	20	7.9
Ictaluridae	<i>Ictalurus punctatus</i>	48	17	7.3
		3	12	86
		3	17	70.5
		3	22	37
		24	12	27
		24	17	20
		24	22	8.2
		96	12	10
		96	17	8.2
		96	22	8.2
	<i>Ictalurus melas</i>	24	12	33.3
		96	12	19.5

Centrarchidae	<i>Lepomis cyanellus</i>	72	20	8.25
	<i>Lepomis macrochirus</i>	24	22	7
		72	20	8.9
	<i>Micropterus salmoides</i>	72	20	7.3
Percidae	<i>Perca flavascens</i>	3	12	7.5
		24	12	4.6
		96	12	3.5
Catostomidae	<i>Ictiobus</i> sp.	24	NR	<8.3
	<i>Catostomus commersoni</i>	96	12	7.2
Poecillidae	<i>Gambusia affinis</i>	1	18	84
		24	NR	17
		24	NR	31

Stream Based Field Studies

Multiple studies have evaluated the effect of rotenone treatments on stream invertebrate communities. One of the most comprehensive studies on the matter was conducted in conjunction with the rotenone treatment of Strawberry Reservoir in 1990. Mangum and Madrigal (1999) evaluated the effects of a 48 hr application of a 3 mg/L (0.15 mg/L active ingredient concentration) rotenone treatment along the Strawberry River. The treatment was repeated twice over a period of two months. The authors found that 59% of the invertebrate taxa in the Strawberry River were removed after the first treatment and 73% were removed after the second treatment (Mangum and Madrigal 1999). Mayflies, stoneflies, and caddisflies were particularly affected by the treatment. The authors found 45-82% fewer Ephemeroptera, 50-69% fewer Plecoptera, and 30-75% fewer Trichoptera species after the first treatment (actual reduction varied with sampling site). Up to 100% of the species from each of these taxa were removed from the ecosystem after the second rotenone application. Mangum and Madrigal (1999) found that depending on sampling location, 9-33% of invertebrate taxa were resistant to the rotenone treatment. After 5 years of sampling, 8-14% of the taxa that were found in the Strawberry River prior to the treatment were still missing from the ecosystem. These missing taxa were primarily mayflies and caddisflies. Conversely, some mayfly and caddisfly species were not eliminated by the rotenone treatment or recovered within a couple of months after treatment. Diptera, primarily chironomids were also heavily affected by the treatment, but were quick to recover.

Other studies have also shown that rotenone treatment can affect aquatic invertebrate communities. Both Arnekleiv et al. (2001) and Kjaerstad and Arnekleiv (2011) evaluated the effects of rotenone treatment (0.5-1.0 mg/L treatment for 7 hrs) on several rivers in Norway and found an immediate increase in the drift of mayflies and as part of the treatment. The authors in both studies estimated that 95-99% of these drifting insects were dead. Insect densities and species diversity did not fully recover after a three year monitoring period. Similarly, Dudgeon (1990) noted an increase in insect drift during a rotenone treatment in Papua New Guinea. Mayflies in the genus *Baetis* were particularly abundant in the drift. Minimal invertebrate mortality and declines in abundance were noted as part of the study. Cook and Moore (1969) found that the rotenone treatment of a small creek in California led to an initial drop in invertebrate abundance but that the population recovered after two months.

Working on another California stream, Finlayson et al. (2010) documented little impact on aquatic insect assemblages after rotenone treatment.

Vinson et al. (2010) provides a synopsis of additional studies that have documented the effects of rotenone treatment on aquatic invertebrate communities (see Table 3 in their article). In general, most studies have shown that rotenone treatment of lotic systems can lead to a reduction in abundance and species richness. There are exceptions, however, where no effect was witnessed. Vinson et al. (2010) also discusses the limitations of much of the previous rotenone research in streams. Primarily, many studies have limited pre-sampling. As a consequence, little is known about the composition of invertebrate communities prior to rotenone application. In fact, the pre-treatment data in many studies are based on a single sample. Also, many studies fail to consider the effect of rotenone application on both density and species richness. Often, the application of rotenone has little effect on invertebrate density but has a strong effect on species richness. Shortly after rotenone treatment, streams are typically dominated with dipterans. It frequently takes 5-10 years for some species of mayflies, caddisflies, and stoneflies to return to treated systems (Vinson et al. 2010). Studies that do not consider the effect of rotenone application on both abundance and richness underestimate the effects of rotenone treatment on invertebrate communities. Also, rotenone concentrations along the banks or streams or in the hyperheic zone are often lower than they are in the thalweg. Species that occupy these areas are less affected by rotenone treatment than thalweg-oriented species (Vinson et al. 2010).

Lake Based Field Studies

Studies have repeatedly demonstrated that rotenone is more toxic to zooplankton than it is to other invertebrates. For example, Rach et al. (1988) showed in the laboratory that the 48 h LC50 for *Daphnia magna* is 0.0037 mg/L. Kiser et al. (1963) found that pelagic zooplankton species were absent for three months after the application of rotenone (0.5 mg/L of 5% powdered rotenone) to a lake in Washington. The effect of the treatment on littoral species was less pronounced (Kiser et al. 1963). Serns and Hoff (1982) found no cladocerans and cyclopoid copepods in Spruce Lake, Wisconsin after the application of a 2.0 mg/L of a 2.5% synergized rotenone solution. It took approximately one year for calanoid copepods to return to the lake. Serns (1979) documented the complete eradication of zooplankton in a second Wisconsin lake following rotenone application (2.5 mg/L of a 2.5% synergized rotenone solution). No zooplankton were documented in the lake for six months after treatment. This particular rotenone treatment occurred in December, which likely slowed the rate of zooplankton community recovery (Serns 1979).

Rotenone application also affects lake insect communities. The effect of rotenone application on lentic insect species is less pronounced as it is for zooplankton. Serns (1979) found a significant reduction in Trichopterans along the 3 m contour of Bug Lake, Wisconsin following the application of a 2.5% synergized rotenone solution (treatment concentration = 2.5 mg/L). A large number of chironomids were observed washing ashore during the rotenone treatment of the lake, but, the number of chironomids killed by the treatment was not enough to cause a significant decrease in chironomid density within the lake. Oligochaetes, odonates, and gastropods appeared to not be affected by the treatment. Burress (1982) noted a 66-97% reduction in benthic invertebrate abundance in experimental ponds 7 d after the application of 2.5% synergized rotenone at concentrations of 2.0 or 5.0 mg/L. The

treatment completely eliminated Trichopterans from the ponds. Many dipterans were also eliminated, but, species from this taxa quickly recolonized the ponds. In contrast, Houf and Campbell (1973) tested rotenone applications of 0.5-2.0 mg/L (5% powdered rotenone) in small experimental ponds and found that rotenone treatment did not influence invertebrate species diversity, abundance, or emergence.

Other reviews have noted that the effect of rotenone application on lentic invertebrate communities varies from application to application (Vinson et al. 2010). These authors note that the variation among studies appears to be caused by an interaction between treatment concentration and exposure duration. Gilderhus et al. (1988) and Dawson et al. (1991) studied factors that influence the persistence of rotenone residues in lentic systems. The half life of rotenone decreases with temperature and increased prevalence of clay sediment and vegetation (Gilderhus et al. 1998; Dawson et al. 1991). It would be expected that rotenone application would have a larger impact on invertebrates in cool, high elevation oligotrophic lakes than in lower elevation eutrophic systems (Dawson et al. 1991). It has been noted that rotenone concentrations are often lower in littoral zones or near the bottom than they are in the pelagic zone (Serns 1979). As a result, burrowing or littoral invertebrate species are less affected by rotenone application than are pelagic or surface oriented species (Serns 1979).

Conclusions

Many studies have assessed the impacts of rotenone application on aquatic invertebrates. Unfortunately, many differences in impact assessment methods and rotenone application techniques (e.g., brand, concentration, exposure duration) exist among these studies. As a result, it is difficult to discern with absolute certainty the effect of rotenone application on aquatic invertebrates. In general, however, it appears that the application of rotenone has an effect on aquatic invertebrate communities. Vinson et al. (2010) outlines several suggestions that could help reduce the effect of rotenone application on aquatic invertebrates. First, historically, higher rotenone concentrations have been used than are necessary for killing fish. Since fish are more sensitive to rotenone than invertebrates (Table 2; Vinson et al. 2010), reduced rotenone concentrations can help minimize the effect of rotenone application on aquatic invertebrates without compromising the goals of the treatment effort (i.e., fish eradication; Finlayson et al. 2010). Second, Vinson et al. (2010) recommend breaking larger drainages into sections for treatment and treating the sections across several years. This allows the un-treated sections to serve as refuges so invertebrates can move into treated sections after rotenone application. Third, fishless headwater stretches should not be treated. This allows these stretches to serve as refuges for invertebrates. Finally, piscicides should be neutralized to minimize impacts on downstream invertebrate communities.

Invertebrates are an important component to aquatic ecosystems. Research has shown that the application of rotenone can have effects on aquatic invertebrate communities. In some situations, the impact of rotenone application on invertebrates can be long lasting (e.g., Mangum and Madrigal 1999). Delays in the re-establishment of invertebrate populations after rotenone application can reduce the establishment success of fish that are stocked after treatment. As a result, it is valuable to consider the effects of rotenone application on aquatic invertebrate communities.

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